CpE 645 Image Processing and Computer Vision

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Image Enhancement

- Point processing:
  - Arithmetic operations
  - Intensity transformations
  - Histogram modifications
- Area processing – filtering:
  - Smoothing, noise reduction
  - Sharpening, edge enhancement

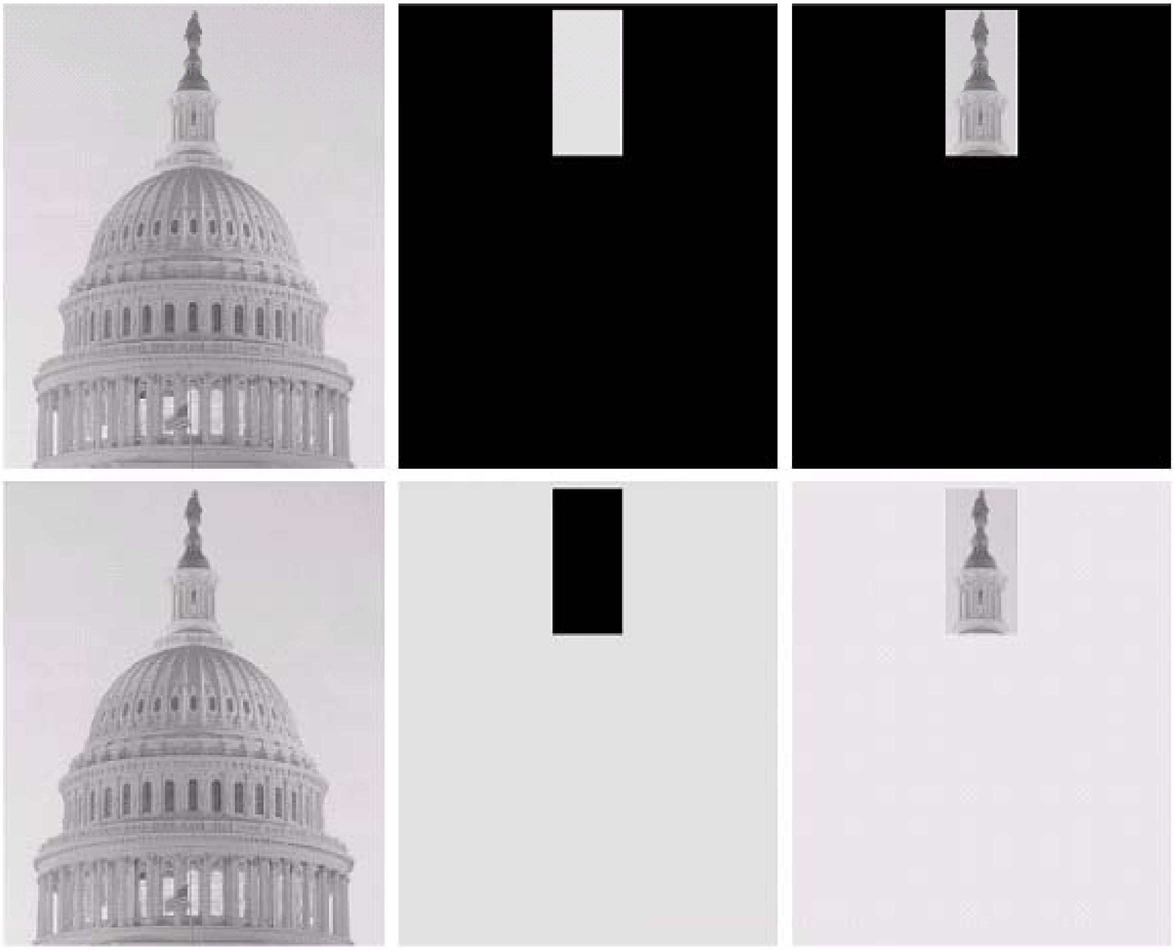
Point Processing

- Point processing operates on each individual pixel (sample) of a digital image.
- Given a pixel amplitude value **r**, which represents the intensity of the light at this sample position, the operator maps it to another value **s** according to a pre-defined function **T**, i.e.

$$\mathbf{s = T(\ r\ ).}$$

- The function **T** can be linear or nonlinear.

Arithmetic Operations



Black = 0

Write = 1

AND

OR

Arithmetic Operations

original

negative: $\mathbf{s = L - 1 - r}$

L = # of levels, e.g. 256

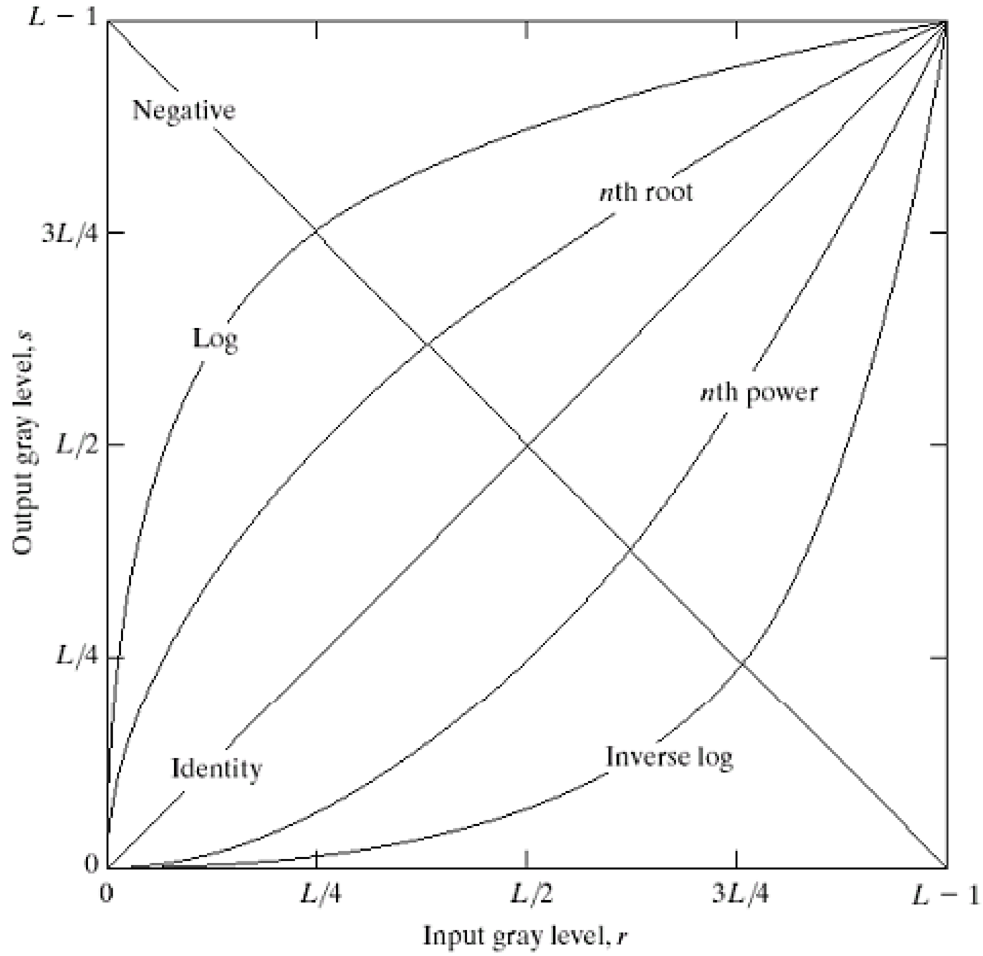
Arithmetic Operations

$s = r - 50$ $\qquad$ $s = r + 50$

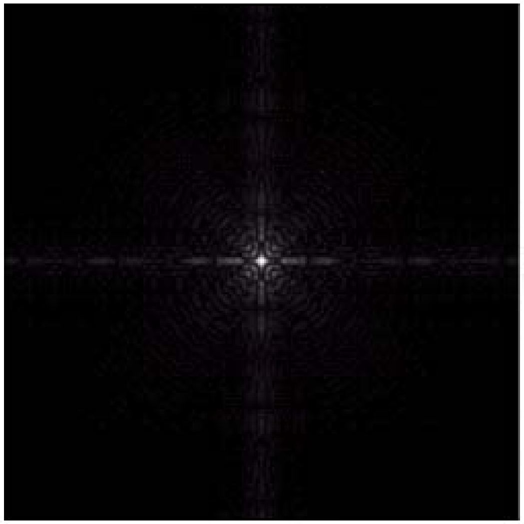
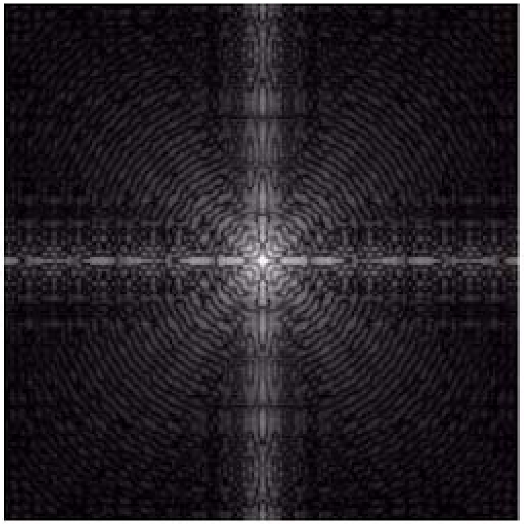
Intensity Transform

- Common intensity transforms:
  (assume input s, output r are real values in [0,1])
  - Identity: $\mathbf{s = r}$
  - Negative: $\mathbf{s = L - 1 - r}$
  - Logarithm: $\mathbf{s = \log_2(1+r)}$
  - Inverse Logarithm: $\mathbf{s = 2^r - 1}$
  - n^{th} power: $\mathbf{s = r^n}$
  - n^{th} root: $\mathbf{s = r^{1/n}}$

Intensity Transform

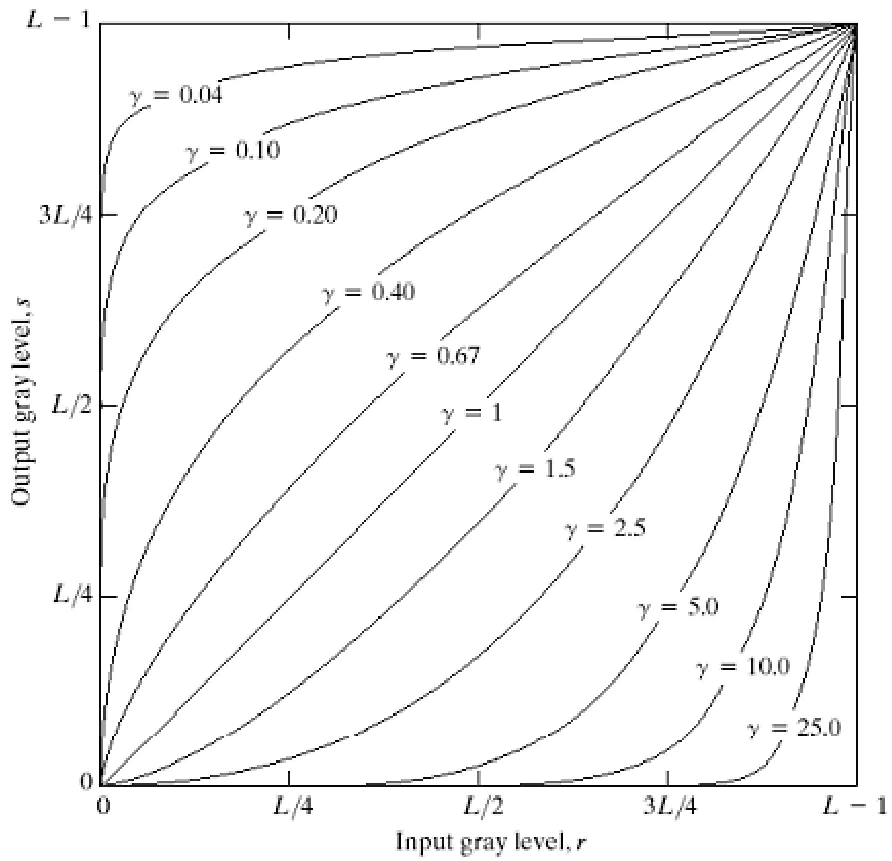


Intensity Transform

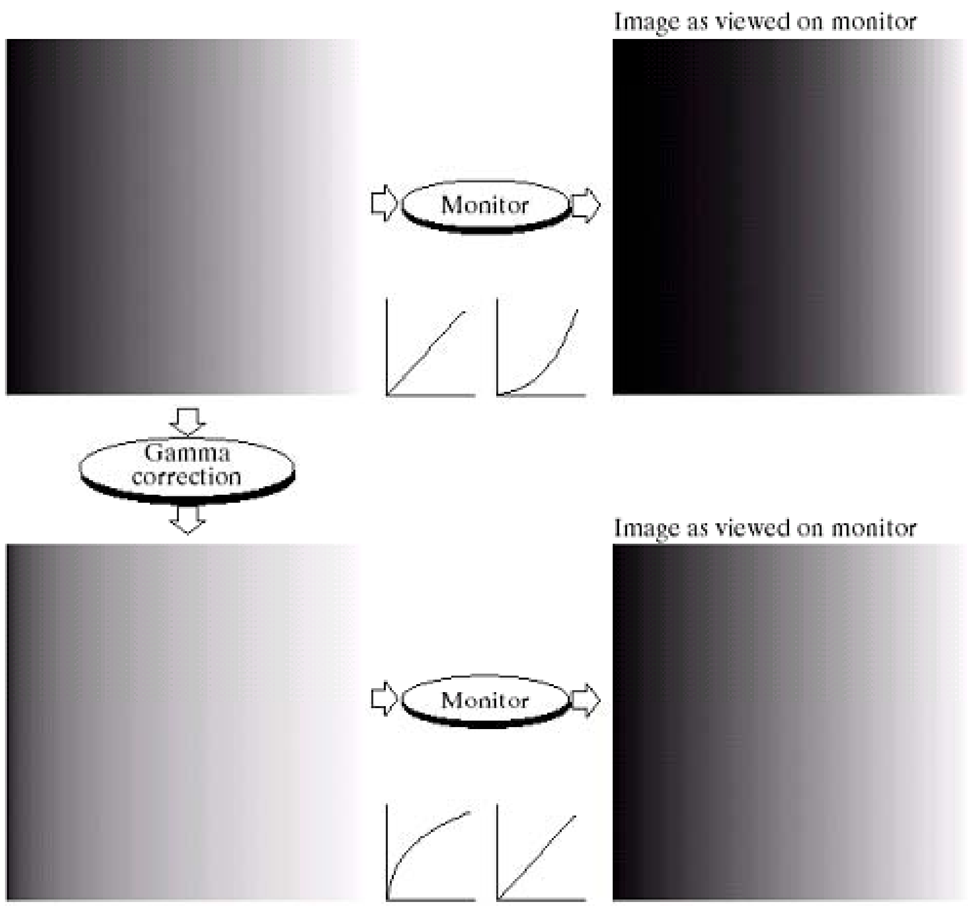
original log transform

Gamma Correction



$\mathbf{s = c \cdot r^{\gamma}}$ (c = 1 in the plot)

Gamma Correction

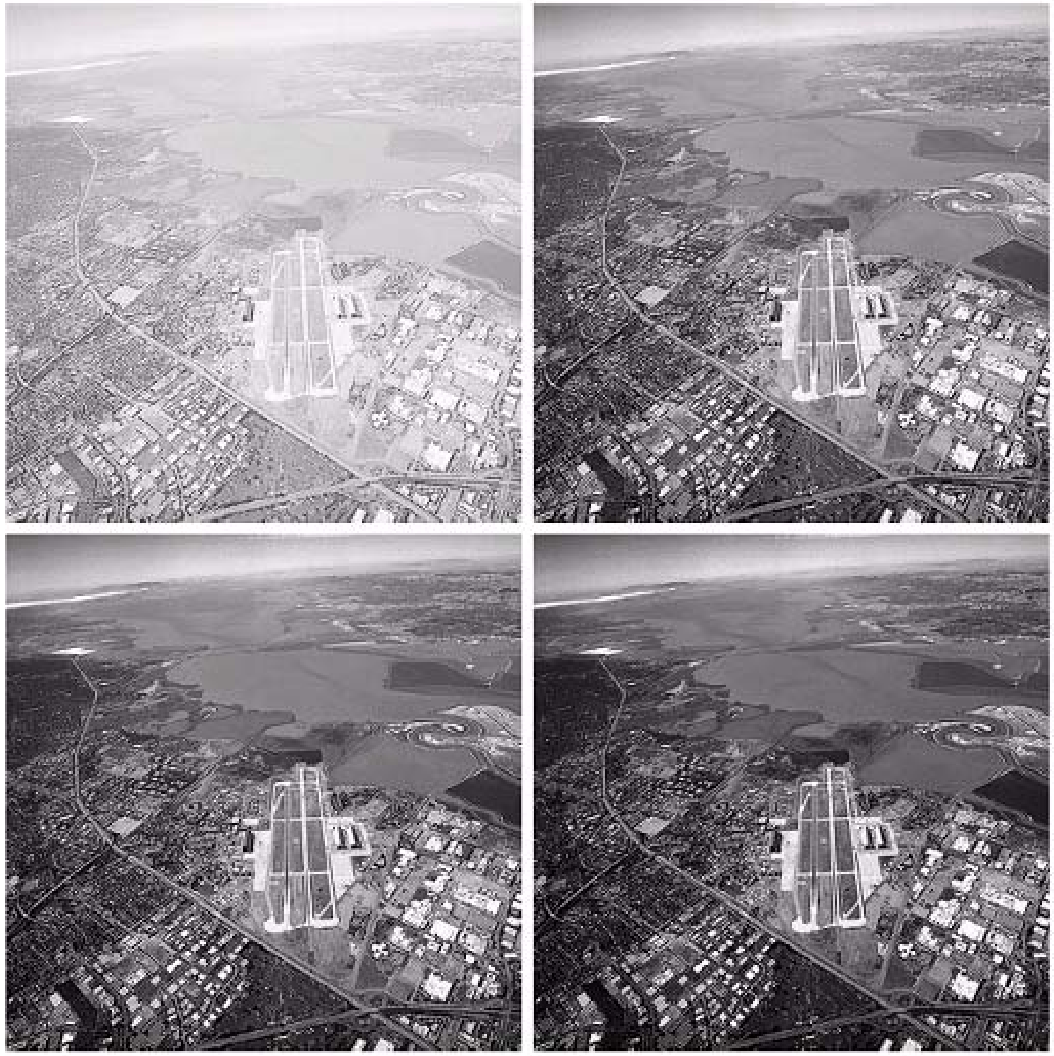


Cathode ray tube (CRT) has a intensity-to-voltage response as a power function, and can be corrected using the gamma correction

Gamma Correction

original

$\gamma = 3.0$



$\gamma = 3.0$

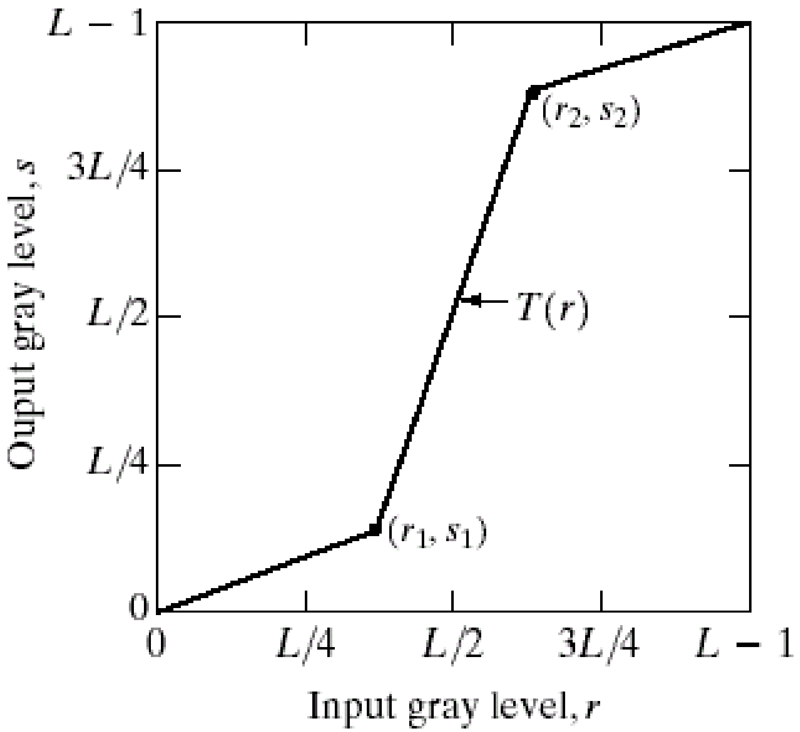
$\gamma = 5.0$

Contrast Stretching

- Contract is a perception of the difference of intensity values among any local image region.
- Poor contrast implies that the image samples in the region have close intensity values.
- Poor contrast can usually be corrected through non-linear intensity transforms.
- Contrast stretching uses a general piece-wise linear transform to enhance the contrast of an arbitrary image.

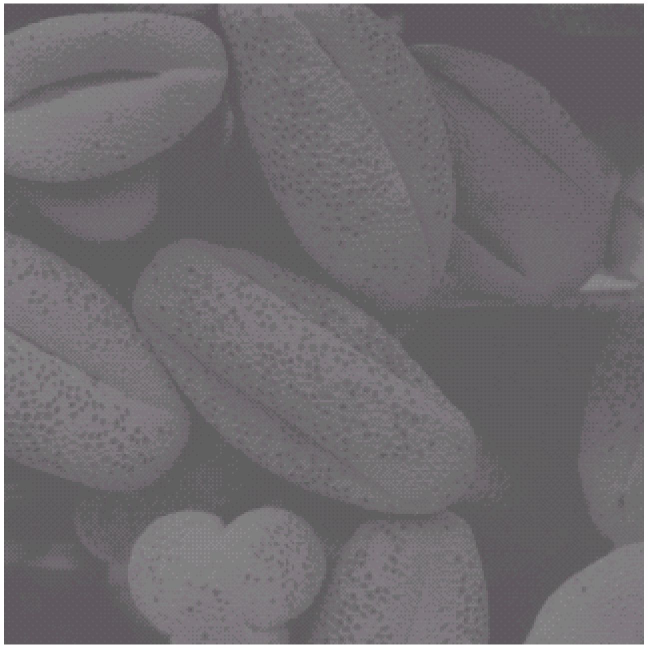
Contrast Stretching

$$s = \begin{cases} \alpha r, & 0 \le r \le r_1 \\ \beta(r - r_1) + s_1, & r_1 \le r \le r_2 \\ \gamma(r - r_2) + s_2, & r_2 \le r \le L-1 \end{cases}$$

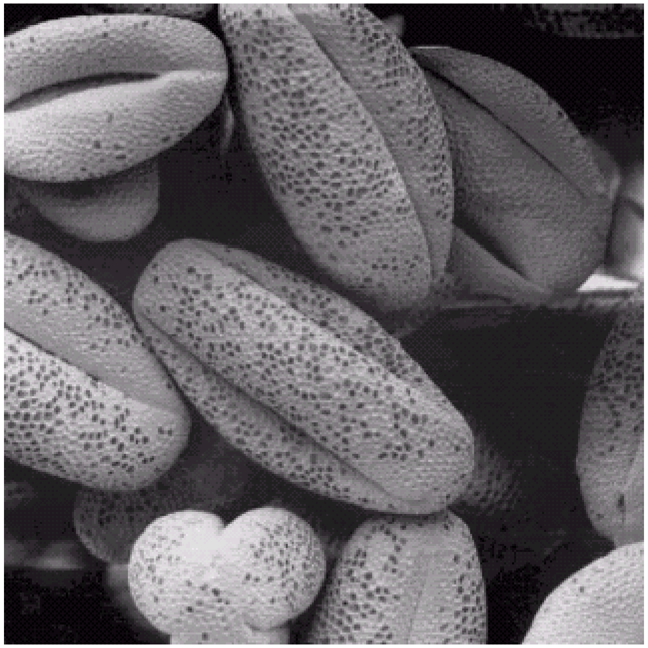


- A general contrast stretching function can have arbitrary number of linear segments, (don't have to be 3 as shown).

Contrast Stretching



original

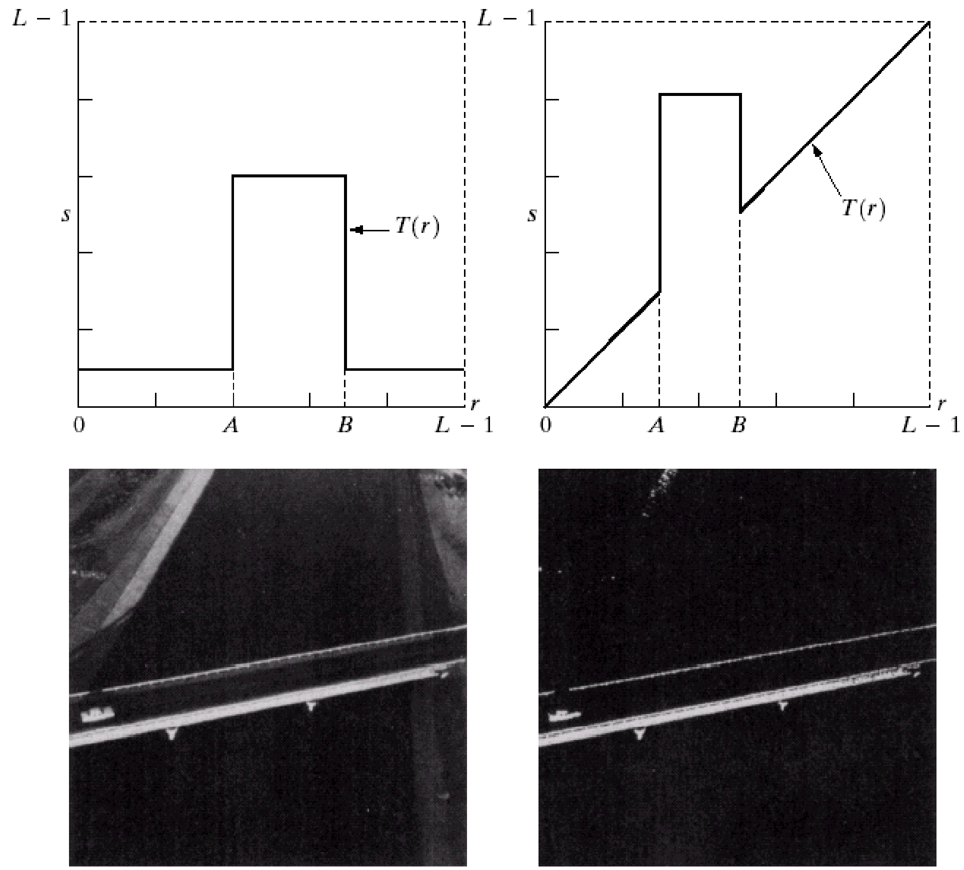


contrast stretched

Contrast Stretching

- Some special cases in contrast stretching
  - if $\mathbf{r_1 = s_1}$ and $\mathbf{r_2 = s_2}$, the transform is linear (no change in contrast)
  - if $\mathbf{r_1 = r_2}$ and $\mathbf{s_1 = 0}$ and $\mathbf{s_2 = L\text{-}1}$, the transform is a thresholding operation
  - if $\boldsymbol{\alpha = \beta = 0}$, or $\boldsymbol{\beta = \gamma = 0}$, the transform is a clipping operation

Gray-Level Slicing



To highlight a specific range of gray levels.

Intensity Transform Summary

- Considerations on the selection of any non-linear intensity transform function:
  - Poor contrast means large amount of samples having very close intensity (amplitude) values.
  - To improve such contrast, we have to find out the ranges of the amplitudes in which these poor contrast samples belong.
  - Use a function with a slope > 1 to expand each of these highly populated ranges.
  - Use a function with a slope < 1 to reduce each of the rest amplitude ranges, so that the output may have a desired dynamic range (usually the same as the input).

Histogram

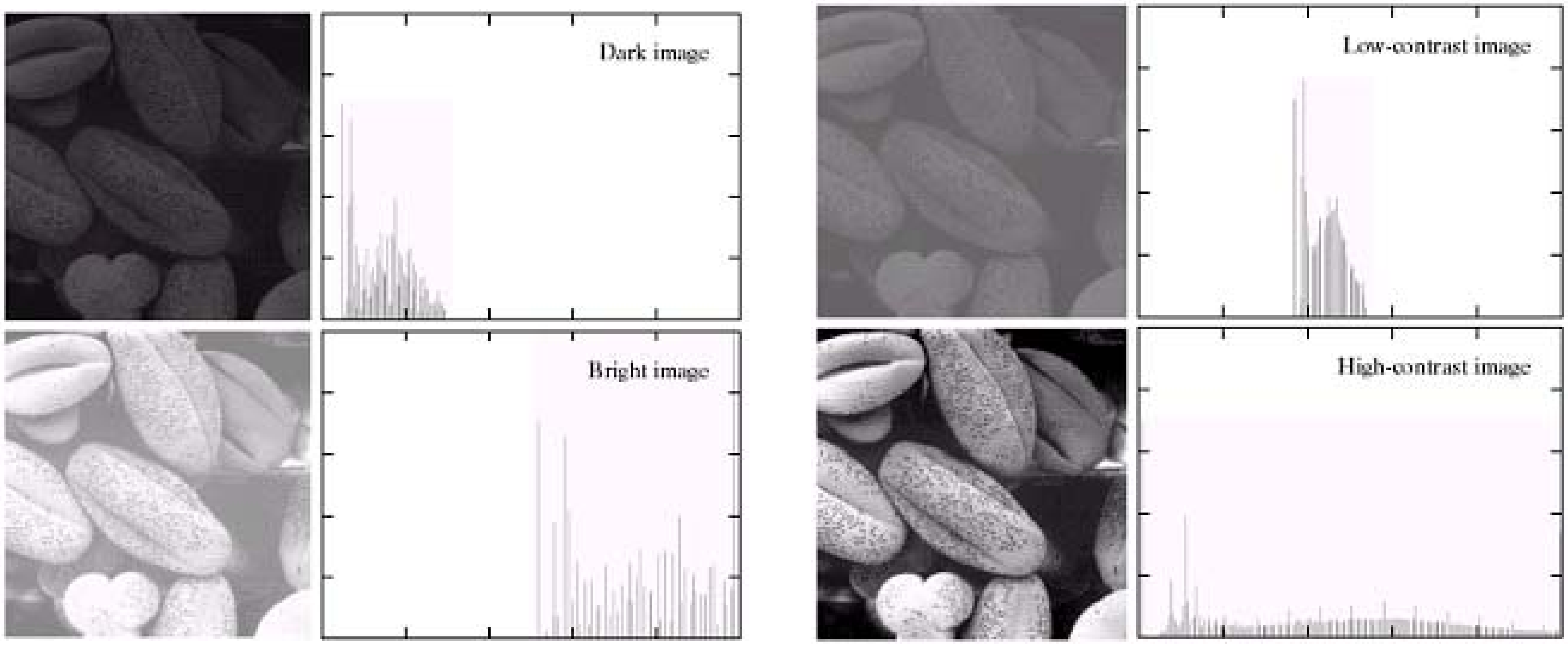
- A histogram is a mapping function that gives the relationship between an amplitude value and the number of occurrences of that value in the image.
- It can be considered as the probability of a certain amplitude value

$$\mathbf{p(r_k)=n(r_k)/N}$$

where $\mathbf{r_k}$ is one of the amplitude values, $\mathbf{n(r_k)}$ is the number of occurrences of $\mathbf{r_k}$, and **N** is the total number of samples (or pixels).

- Histogram provides a global description of the appearance of an image, especially the brightness and the contrast.

Histogram Examples



Histogram Equalization

- First we recognize that $\sum_k \mathbf{p(r_k)} = \sum_k \mathbf{n(r_k)/N = 1}$
- We seek a transformation that can convert an input $\mathbf{p_i(r)}$ to an equalized $\mathbf{p_e(r)}$**,** which has a more uniform distribution.
  - This function should be monotonically increasing.
  - This function should satisfy $\sum_k \mathbf{p_e(r_k) = 1}$
- An example of this function in discrete domain is

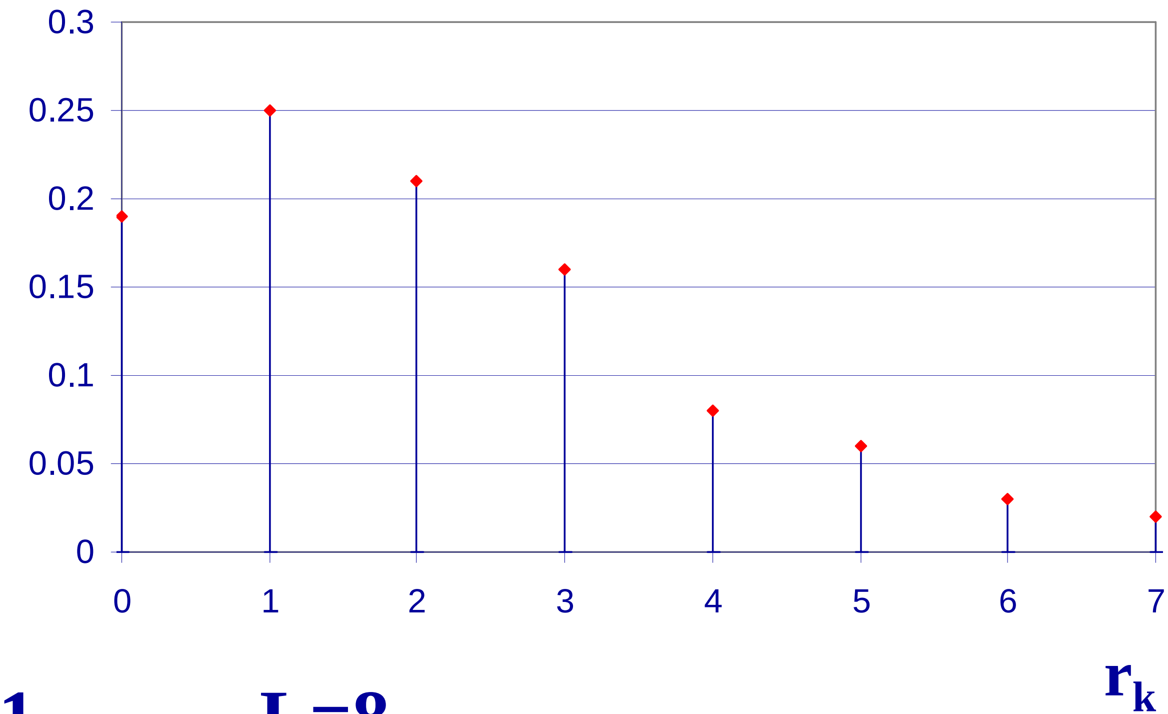
$$s_l = T(r_l) = Round\left\{(L-1)\sum_{k=0}^{l} p_i(r_k)\right\}$$

where **L** is the number of all possible amplitude values, and $l \in \{0, 1, 2, \ldots, L-1\}$

Histogram Equalization

- $p_i(r_0)=0.19$
- $p_i(r_1)=0.25$
- $p_i(r_2)=0.21$
- $p_i(r_3)=0.16$
- $p_i(r_4)=0.08$
- $p_i(r_5)=0.06$
- $p_i(r_6)=0.03$
- $p_i(r_7)=0.02$

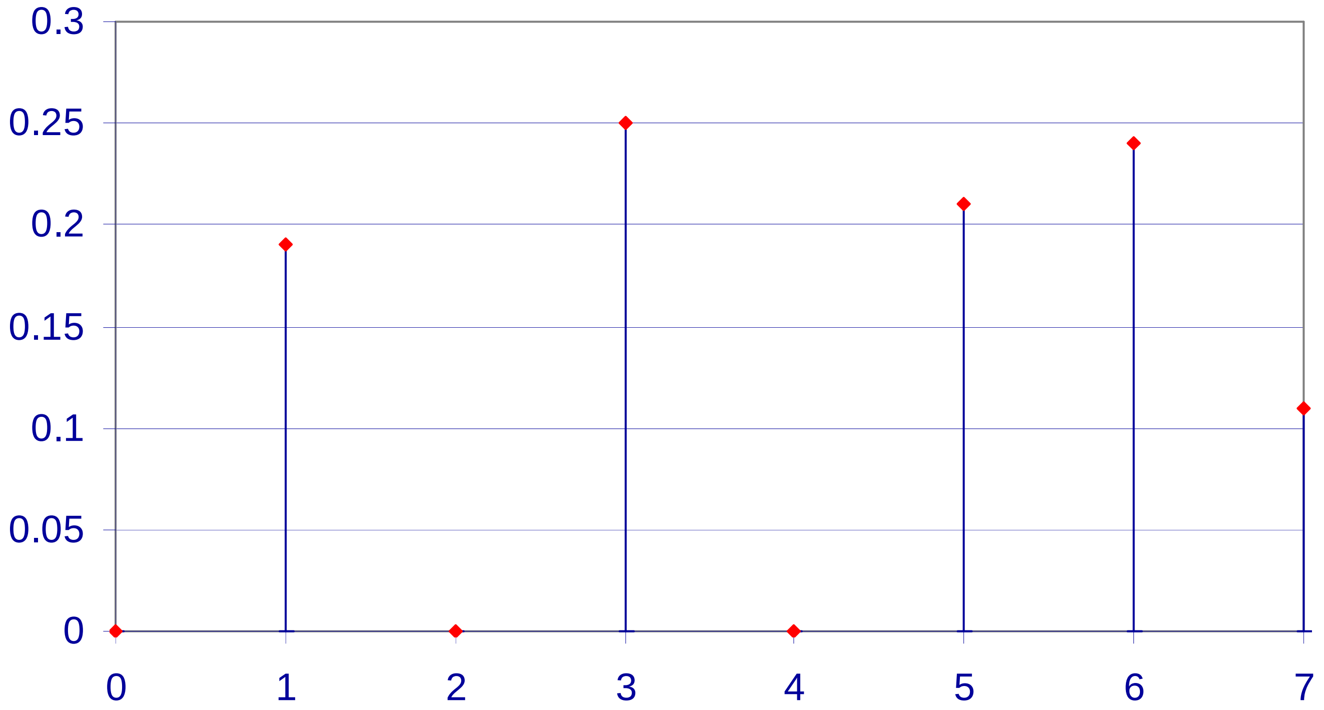
$\sum_k p_i(r_k) = 1$, $L=8$



Histogram Equalization

$$s_0 = Round\left\{(8-1)\sum_{k=0}^{0} p_i(r_0 = 0)\right\}$$
$$= Round\{7 \times .19\} = 1$$
$$s_1 = Round\{7 \times (.19 + .25)\} = 3$$
$$s_2 = Round\{7 \times (.19 + .25 + .21)\} = 5$$
$$s_3 = Round\{7 \times (.19 + .25 + .21 + .16)\} = 6$$
$$s_4 = Round\{7 \times (.19 + .25 + .21 + .16 + .08)\} = 6$$
$$s_5 = Round\{7 \times (.19 + .25 + .21 + .16 + .08 + .06)\} = 7$$
$$s_6 = Round\{7 \times (.19 + .25 + .21 + .16 + .08 + .06 + .03)\} = 7$$
$$s_7 = Round\{7 \times (.19 + .25 + .21 + .16 + .08 + .06 + .03 + .02)\} = 7$$

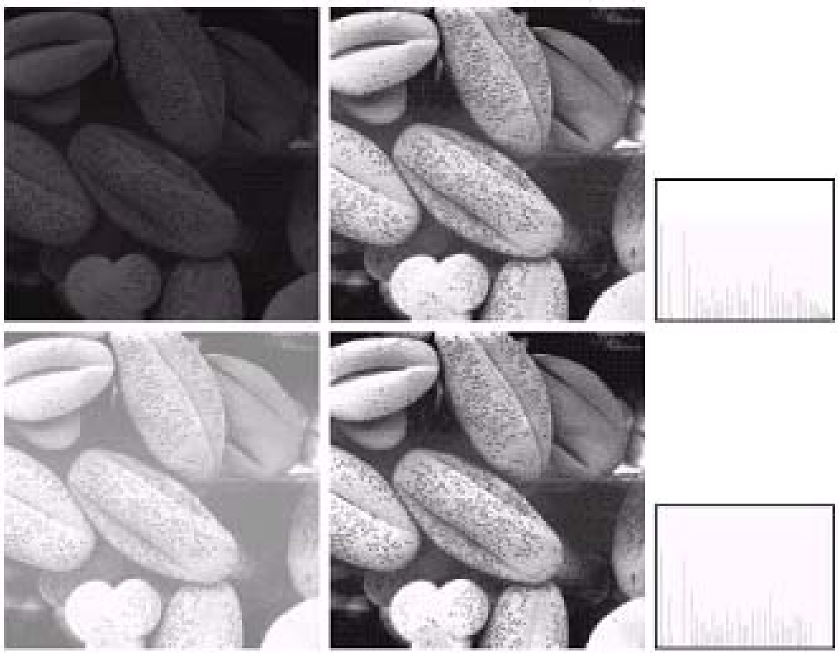
Histogram Equalization



Equalized histogram with spread distribution

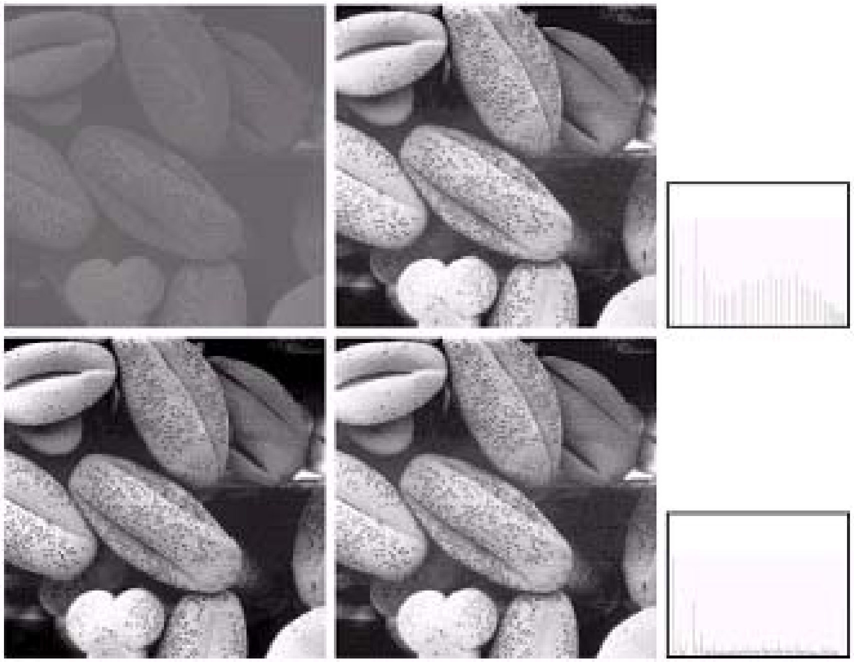
Histogram Equalization Examples

(1)



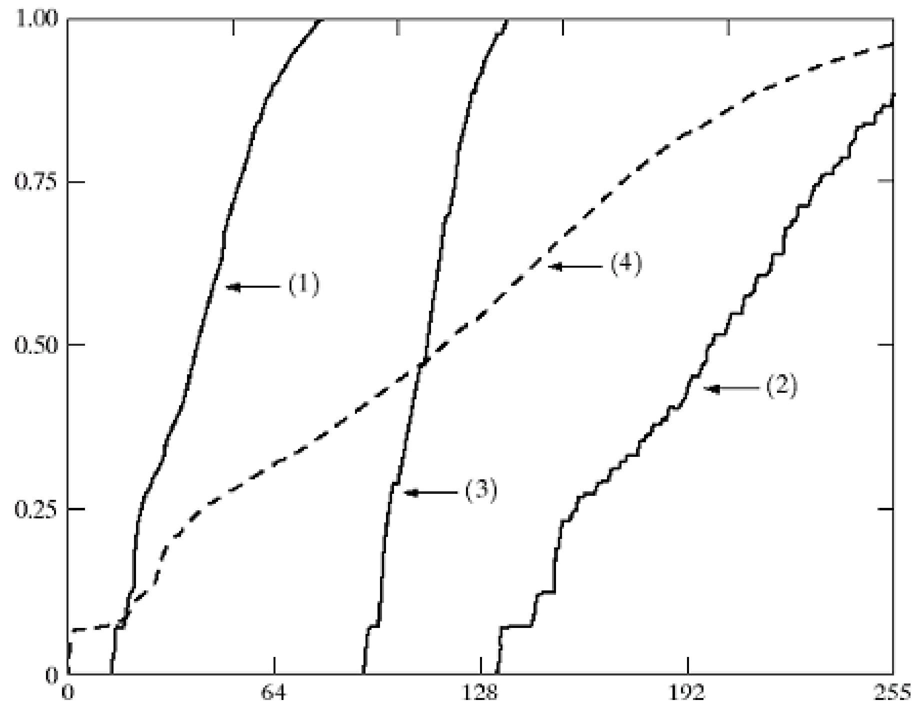
(2)

(3)



(4)

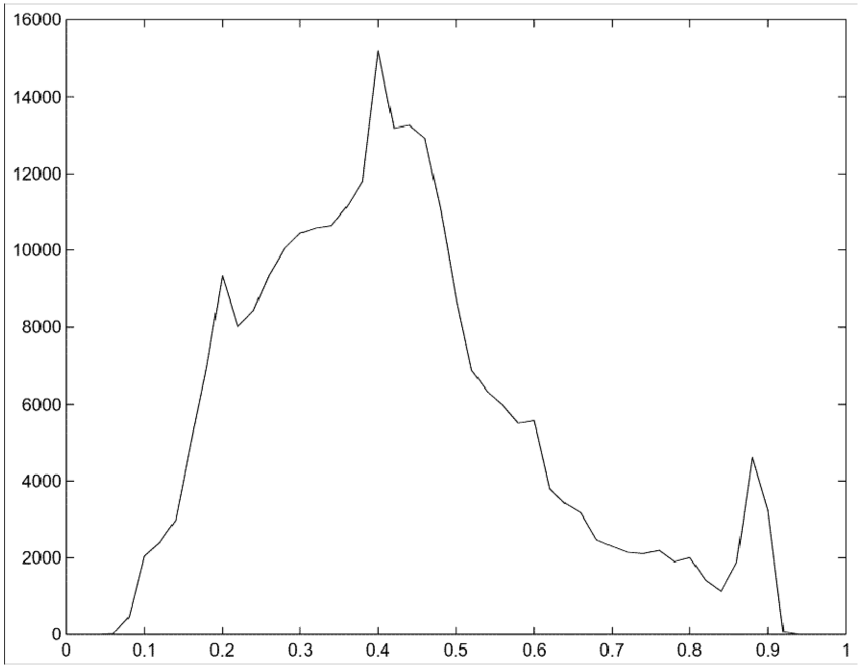
Transformation Function



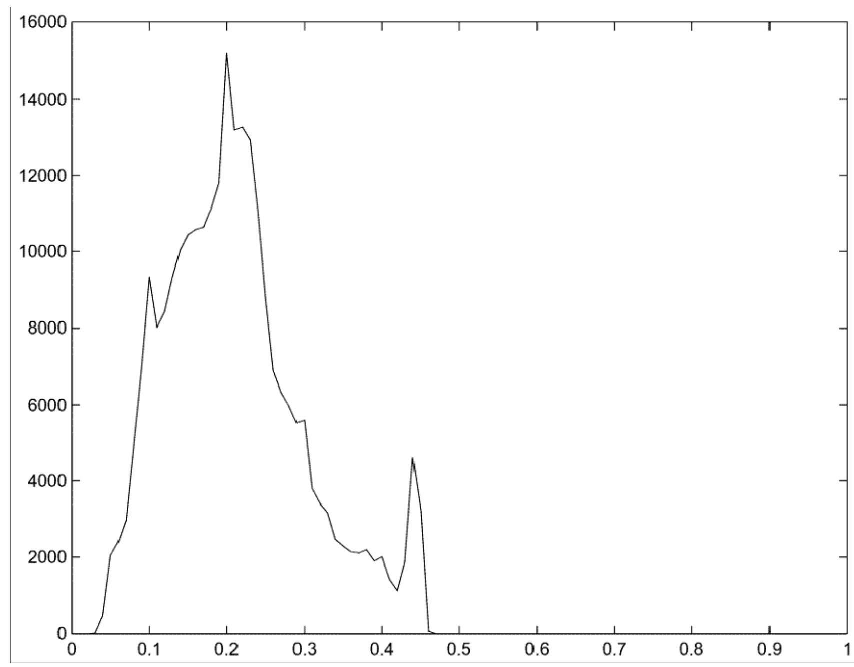
Transformation functions calculated from histogram equalization.

Histogram Example

Original

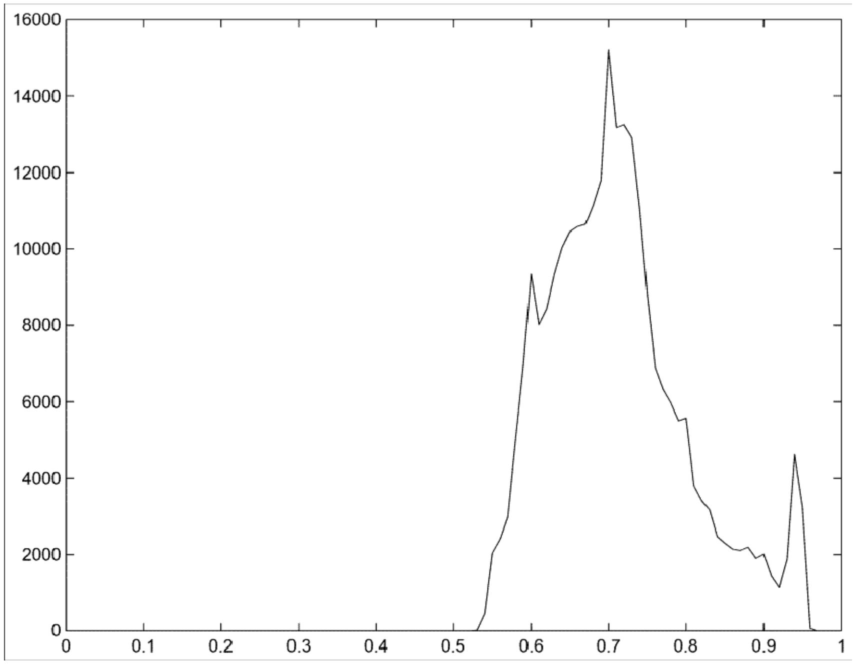


Histogram Example



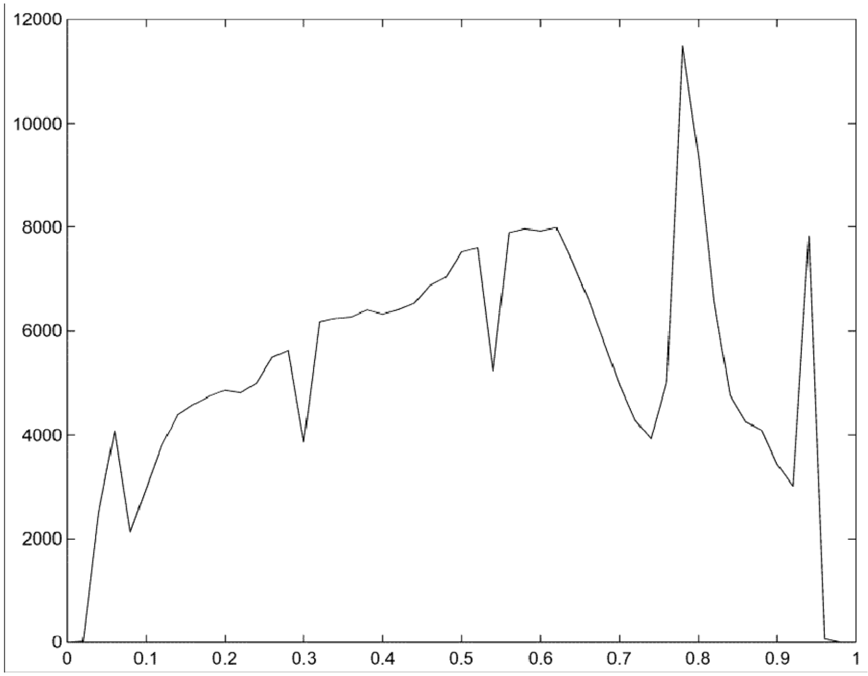
Poor contrast

Histogram Example



Poor contrast

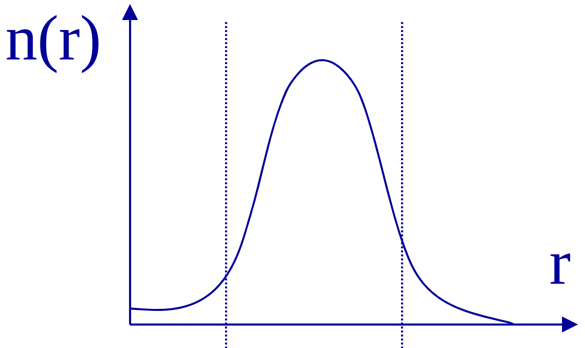
Histogram Example



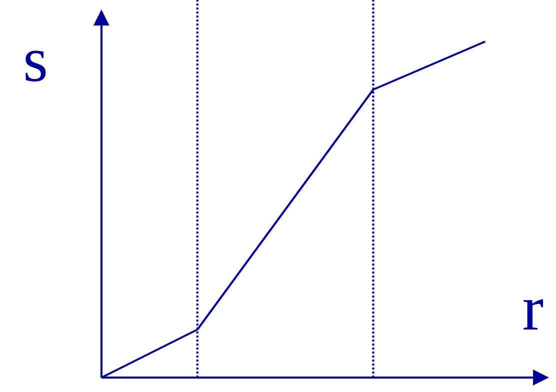
Enhanced contrast

Histogram in Contrast Stretching

- Histogram is frequently used in the design of contrast stretching function.
- The goal is to obtain a relatively flat, spread distribution of the histogram.
- Each of the stretching segment (slope > 1) should correspond to a peak (concentrated distribution) in the histogram.



histogram



stretching function